# Curved Waveguide-Based Nuclear Fission for Small, Lightweight Reactors

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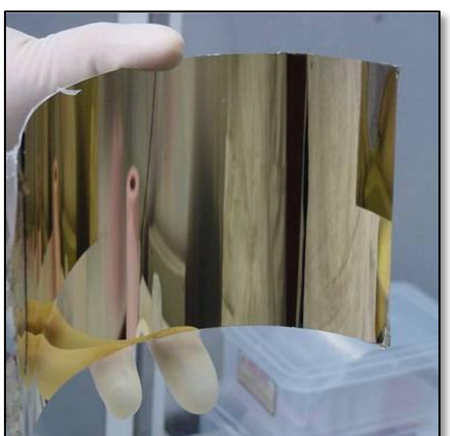
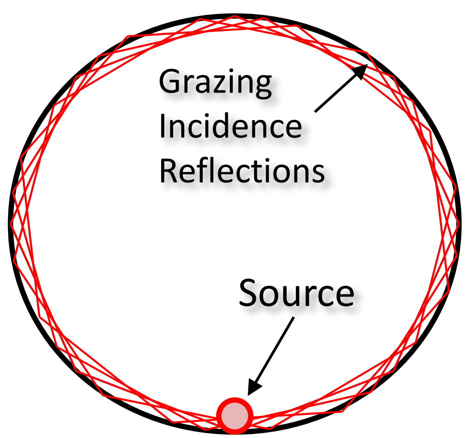
# Executive Summary

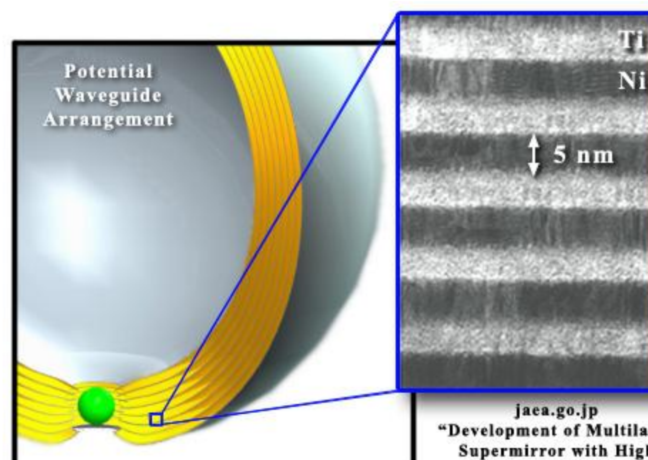
- Goal: Small, lightweight fission reactor suitable for use in deep space applications (e.g., power supply, propulsion, etc.)

- Primary Innovation
  - Capture and reuse free neutrons to sustain and/or accelerate fission.
  - Accomplished using grazing incidence, layered super-mirror.
  - No similar method of neutron capture and reuse has been disclosed.

- Basic Concept
  - Fabricate highly curved, neutron super-mirrors using known methods of Ni-Ti layering.
  - Arrange mirrors around radioactive material to maximize entrapped area of source.
  - Use whispering gallery behavior of mirrors and shallow incidence angle reflections to capture neutrons and return them to source material to sustain fission.



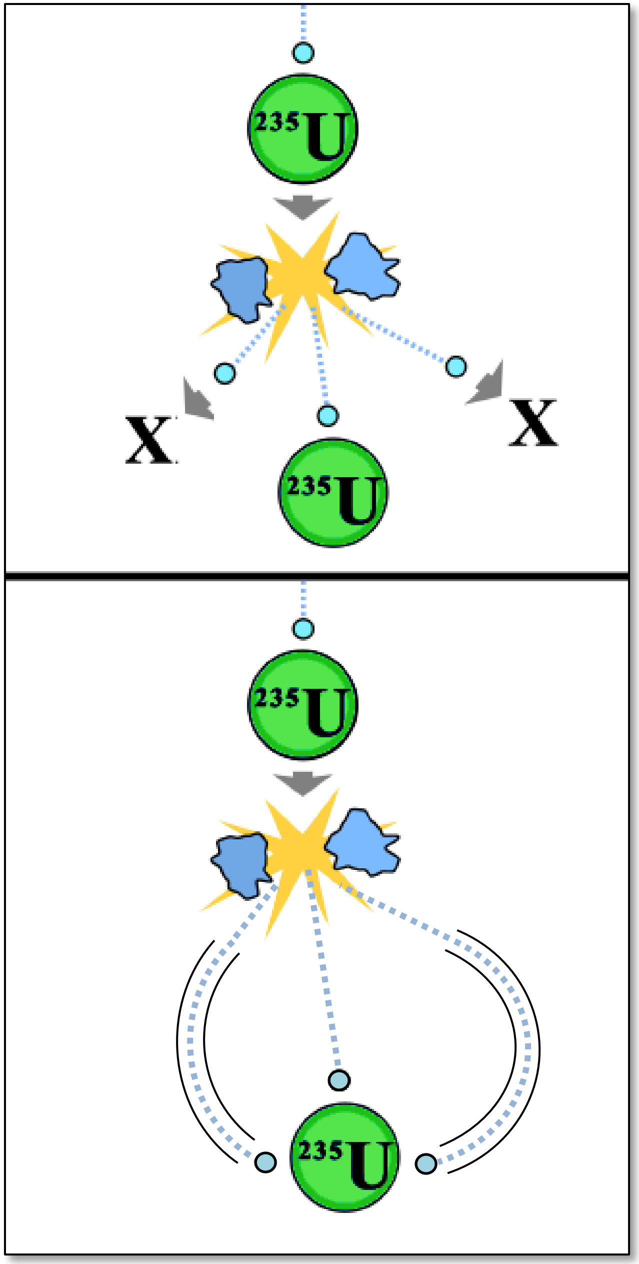



jaea.go.jp
"Development of Multilayer Supermirror with High Reflectivity"

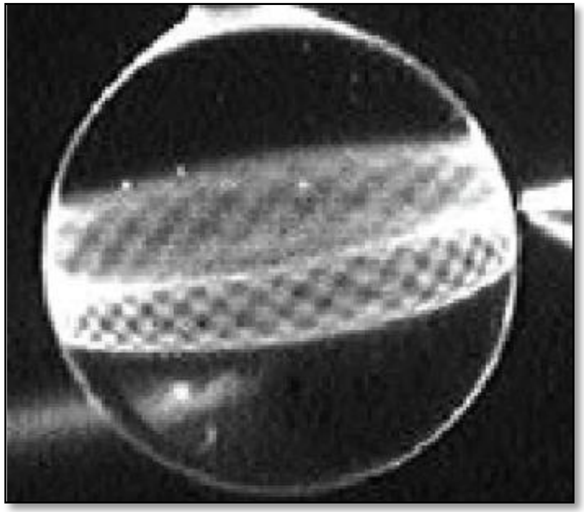
# Technical Details

- Normal Reactor Losses
  - Escaping neutrons absorbed / partially reflected in nearby shielding material.
  - Neutrons beta decay without reacting.
- Proposed Design
  - Neutrons captured by grazing optics and channeled back to fissile material.
  - Lowers rate of neutron escape from material.
  - Increases neutrons available to sustain the chain-reaction.
  - Effectively acts as shielding.
- Ideal System Limit
  - All neutrons perfectly captured and reused instantaneously
  - Required fissile mass approaches zero.
  - Ignores issues of emitted vs usable energies
  - Ignores issue of producing useful energy

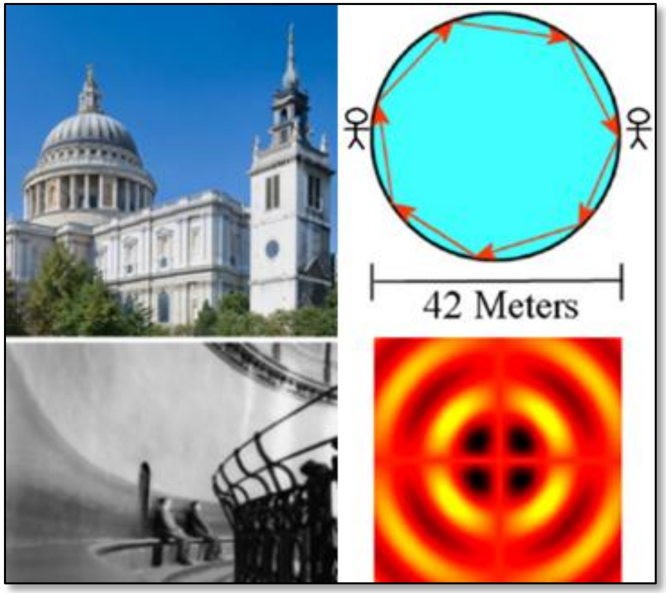


# Technical Details

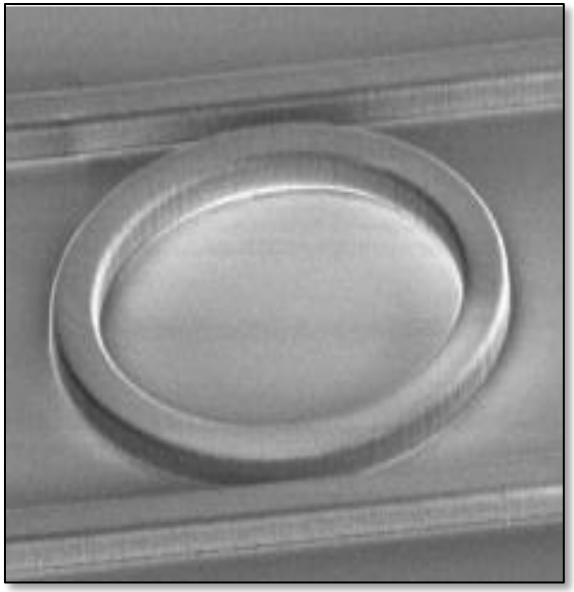
- Fundamental principles are well grounded in other wave-like phenomena
  - Whispering galleries in acoustics.
    - St. Pauls, Gul Gumbaz, Temple of Heaven
    - Ellipsoid Reflectors
  - Optical ring resonators



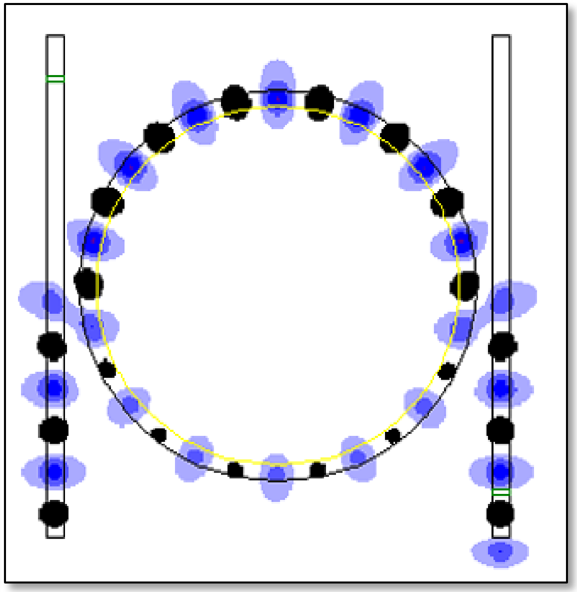
*Optical Whispering Gallery Modes within a Glass Sphere, NASA/JPL*




*Whispering Gallery Effect at St. Paul's*



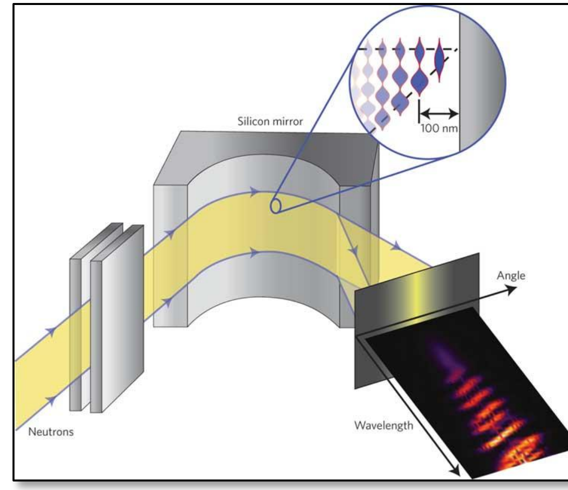
*Optical Ring Resonator*



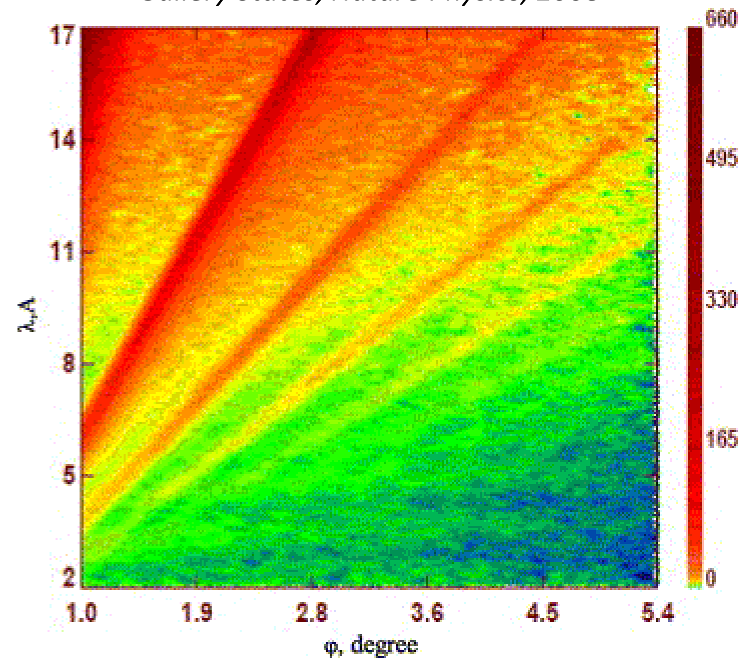
*Optical Ring Resonator Modes*

# Technical Details

- *Neutron* whispering gallery states recently demonstrated
  - Nature Physics, 2008 (ILL, Grenoble)
  - Small angle turning of beam
  - Ultra-cold to cold neutrons
- Shows possibility for long-lived neutron quantum states at thermal and higher energies.
- Present neutron storage devices require large superconducting magnets and cold traps.
- Need a geometry to store and then deliver neutrons.




*Demonstration of Neutron Whispering Gallery States, Nature Physics, 2008*

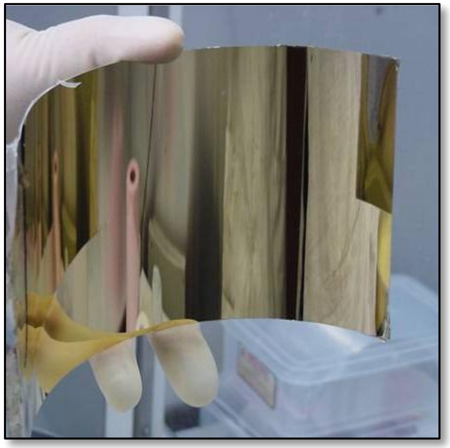


# Technical Details

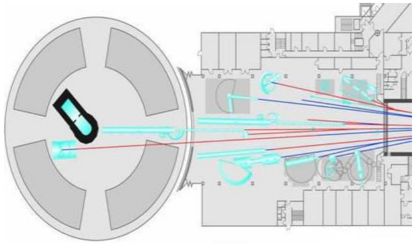
## Grazing Incidence Thermal Neutron Guides

- Well known tool for directing neutrons from a source (such as a reactor core) to more accessible locations.
- Under small incidence angles, achieve nearly lossless neutron transport.
- Interiors are plated with nickel or alternating layers of nickel and titanium.
- Layering has achieved grazing angles four times as steep as nickel alone.
- Operates with similar reflectivities as X-rays
  - Similar momenta and wavelengths (~few Å)
  - Allows leverage of expertise for telescope optics

*Common Neutron Guides*

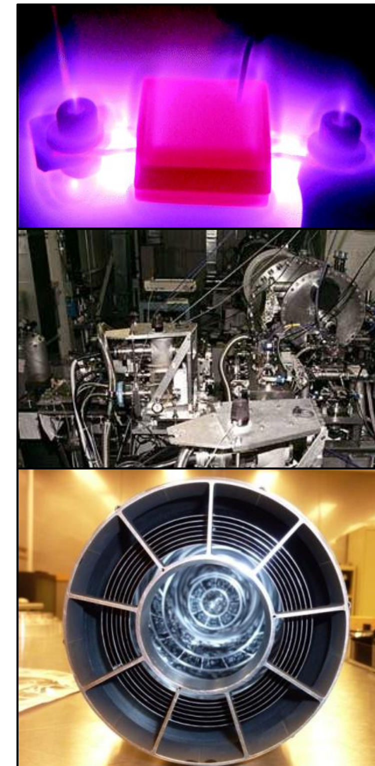


*Example of Curved Grazing Incidence Mirror*



# Existing NASA Investments

- Manufacturing / IP
  - Thin film metal deposition technologies and facilities
    - Electroplating baths
    - Vapor deposition systems
    - Largely unused in many cases
  - Waveguide and support structure fabrication
    - Rapid prototyping facilities at numerous centers
  - X-ray source, imaging, and testing facilities
    - Testing facilities developed for telescope optics and NDE.
  - Existing patents for grazing incidence optics



- Existing NASA Partnerships (Primarily Science Dir.)
  - Partnerships with neutron sources (MIT, Oak Ridge)
  - Partnerships with inexpensive optics fabrication shops (Harvard Smithsonian)

- Much of the infrastructure needed for development of this new technology already exists within NASA or partners.

# Projected Milestones

- Develop design for easily fabricated, supermirror waveguide testing assembly
  - Considering flat panels bent into final shape
  - Initial ring evolving to more efficient /complicated geometries

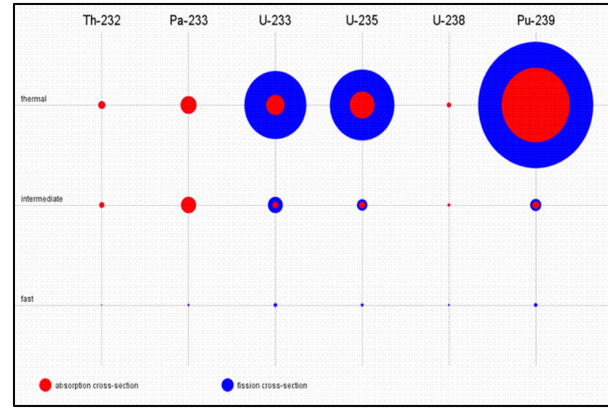
- Demonstrate 180-360 degree neutron turning
  - Measure output states relative to inputs
  - Evaluate impact of quantum effects
  - Initially sub-thermal neutrons with low-energy (desktop) source

- Demonstrate turning for higher energy neutrons
  - Thermal and fast neutrons typical of fission
  - Likely require future collaboration with a DOE facility.

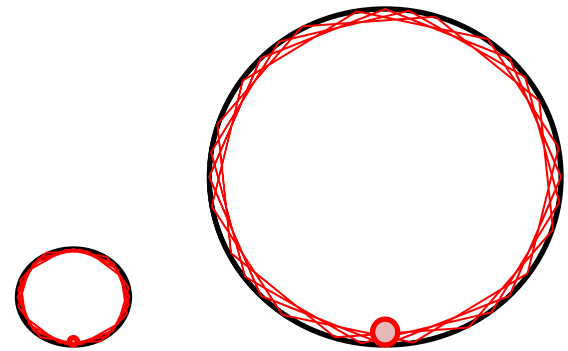
- Demonstrate turning with radioactive material (DOE)
- Demonstrate fission with radioactive material (DOE)

# Potential Issues

- Mismatch of emitted to useful neutrons
  - Fission emits Max-Boltz distribution from 0-14 MeV
  - Common fuels rarely react (have a small cross section) to fast (~1 MeV) neutrons (ex: U-235, P-239)
  - Layering may also make guide wavelength sensitive.
  - Probably requires a moderator to increase cross section.
  - Moderator also helps with next issue.




- Final reactor size
  - Even 4x turning angle is only ~0.7 deg. for thermal neutrons.
  - Significantly less for fast (1 MeV) neutrons.
  - Size of thermal reactor is reasonable (~0.5-1.0 m)
  - Fast version is enormous.

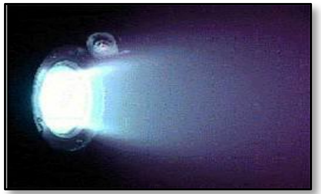


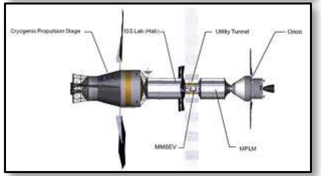
- Safety
  - Initial design has no natural damping mechanism.
  - Normal reactors spread the fuel as they heat up.
  - May need active control to stop runaway (or clever design)

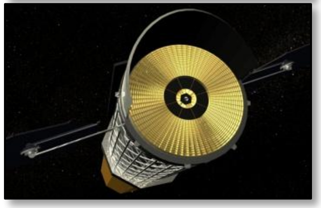
# Alignment & Value

- Value
  - High energy density, low mass power source
  - Potential for sustaining fission with a fraction of normal critical mass.
  - Broaden range of fuels due to reduced release, absorption, and non-fission rates.
  - Meets national needs for highly efficient, clean energy sources.
  - Improves use of low grade or partially depleted fissile materials.
  - Reduces national stockpiles and waste.

- Aligned Subject Areas
  - Advanced in-space propulsion
    - Source  of secondary energy for high impulse electric.
    - Applicable for decadal study missions using probes to the heliosphere.
  - In-space habitation
    - Larger number of power intensive nodes used for the same habitation system.
    - Particularly useful for Deep Space Habitat where solar power is minimal.
  - Landers / Sample Return
    - Power for drilling polar regions of Mars, and permanent shadow regions of moon.
    - Missions beyond Mars require nuclear power because sunlight is too weak.
    - Limited # of radioisotope systems is constraint on missions to outer solar system.
    - Letters of interest from planetary decadal survey authors.
  - X-ray telescope
    - Tech for neutron super-mirrors is directly applicable to fabrication of x-ray optics.
    - Letters of interest from x-ray telescope scientists





# Questions?